CLAIMS

What is claimed is:

1. An electromagnetic product, comprising:

   at least two coplanar magneto-resistive sensors, each magneto-resistive sensor having a sensitive axis in the plane of the at least two coplanar magneto-resistive sensors.

2. An electromagnetic product according to claim 1, wherein at least one magneto-resistive sensor comprises a giant magneto-resistive sensor.

3. An electromagnetic product according to claim 1, wherein the at least two coplanar magneto-resistive sensors are orthogonally arranged to measure orthogonal components of an electromagnetic field.

4. An electromagnetic product according to claim 1, wherein the at least two coplanar magneto-resistive sensors are orthogonally arranged about a central point.

5. An electromagnetic product according to claim 1, wherein each magneto-resistive sensor comprises a pair of sensing resistors and a pair of electromagnetically shielded resistors, the sensing resistors and the shielded resistors arranged in a bridge configuration.

6. An electromagnetic product according to claim 1, wherein the at least two coplanar magneto-resistive sensors are deposited on a substrate.

7. An electromagnetic product according to claim 1, further comprising a flux concentrator to enhance sensitivity.

8. An electromagnetic product according to claim 1, further comprising at least one coil providing a bias.

9. An electromagnetic product according to claim 1, further comprising at least one magnet providing a bias.

10. An electromagnetic product for measuring an electromagnetic field in two dimensions, comprising:

a first and a second giant magneto-resistive sensor, the first and second giant magneto-resistive sensors having a coplanar relationship and arranged in a cruciform about a central point, the first giant magneto-resistive sensor having a first sensitive axis in the plane for measuring an electromagnetic field along the first sensitive axis, the second giant magneto-resistive sensor having a second sensitive axis in the plane for measuring the electromagnetic field along the second sensitive axis, the first and second giant magneto-resistive sensors measuring orthogonal components of the electromagnetic field in an area of the central point.

11. An electromagnetic product, comprising:

a plurality of devices, each device in the plurality of devices comprising at least one pair of coplanar magneto-resistive sensors, each magneto-resistive sensor having a sensitive axis in the plane and measuring an electromagnetic field along the sensitive axis.

12. An electromagnetic product according to claim 11, wherein at least one pair of coplanar magneto-resistive sensors comprises at least one giant magneto-resistive sensor.

13. An electromagnetic product according to claim 11, wherein the plurality of devices is formed on a substrate.

14. An electromagnetic product according to claim 11, wherein the plurality of devices is formed on multiple substrates.

15. An electromagnetic product according to claim 11, wherein the plurality of devices are formed on substrates arranged in a stack.

16. An electromagnetic product according to claim 11, wherein the plurality of devices is formed on at least one substrate, and wherein the at least two coplanar magneto-resistive sensors are orthogonally arranged about a central point.

17. An electromagnetic product according to claim 11, wherein the plurality of devices are arranged in an array.

18. An electromagnetic product, comprising:

a plurality of devices formed on a substrate, the plurality of devices arranged in an array, each device comprising a first and a second giant magneto-resistive sensor;

the first and second giant magneto-resistive sensors having a coplanar relationship and arranged in a cruciform about a central point, the first giant magneto-resistive sensor having a first sensitive axis in the plane and measuring the electromagnetic field along the first sensitive axis, the second giant magneto-resistive sensor having a second sensitive axis in the plane and measuring the electromagnetic field along the second sensitive axis, the first and second giant magneto-resistive sensors measuring orthogonal components of the electromagnetic field in an area of the central point.

19. An electromagnetic product, comprising:

at least two coplanar magneto-resistive sensors, each magneto-resistive sensor having a sensitive axis in the plane of the at least two coplanar magneto-resistive sensors; and

a third sensor sensitive to the electromagnetic field in a direction perpendicular to the at least two coplanar magneto-resistive sensors,

wherein the electromagnetic product measures an electromagnetic field in three dimensions.

20. An electromagnetic product according to claim 19, wherein at least one magneto-resistive sensor comprises a giant magneto-resistive sensor.

21. An electromagnetic product according to claim 19, wherein at least one magneto-resistive sensor comprises a spin-dependent tunneling sensor.

22. An electromagnetic product according to claim 19, wherein at least one magneto-resistive sensor comprises an anisotropic magneto-resistive sensor.

23. An electromagnetic product according to claim 19, wherein the third sensor utilizes the *Hall effect* to measure the electromagnetic field.

24. An electromagnetic product according to claim 19, wherein the third sensor comprises a geometric magneto-resistive sensor to measure the electromagnetic field.

25. An electromagnetic product according to claim 19, wherein the third sensor comprises a coil.

26. An electromagnetic product according to claim 19, wherein the at least two coplanar magneto-resistive sensors are orthogonally arranged to measure orthogonal components of the electromagnetic field.

27. An electromagnetic product according to claim 19, wherein the at least two coplanar magneto-resistive sensors are orthogonally arranged about a central point.

28. An electromagnetic product according to claim 19, wherein the at least two coplanar magneto-resistive sensors and the third sensor are orthogonally arranged about a central point.

29. An electromagnetic product according to claim 19, wherein the at least two coplanar magneto-resistive sensors are formed on a substrate.

30. An electromagnetic product according to claim 19, wherein the at least two coplanar magneto-resistive sensors and the third sensor are formed on a substrate.

31. An electromagnetic product according to claim 19, wherein the at least two coplanar magneto-resistive sensors are arranged in a bridge configuration.

32. An electromagnetic product according to claim 19, further comprising a flux concentrator to enhance sensitivity of the electromagnetic product.

33. An electromagnetic product according to claim 19, further comprising at least one coil providing a bias.

34. An electromagnetic product according to claim 19, further comprising at least one magnet providing a bias.

35. An electromagnetic product for measuring an electromagnetic field in three dimensions, comprising:

a first and a second giant magneto-resistive sensor, the first and second giant magneto-resistive sensors having a coplanar relationship and arranged in a cruciform about a central point, the first giant magneto-resistive sensor having a first sensitive axis in the plane and measuring the electromagnetic field along the first sensitive axis, the second giant magneto-resistive sensor having a second sensitive axis in the plane and measuring the

electromagnetic field along the second sensitive axis, the first and second giant magneto-resistive sensors measuring orthogonal components of the electromagnetic field in an area of the central point; and

a third sensor arranged in the area of the central point, the third sensor utilizing the *Hall effect* to measure the electromagnetic field in a direction perpendicular to the plane of the first and second giant magneto-resistive sensors,

wherein the electromagnetic product measures the electromagnetic field in three dimensions in the area of the central point.

36. An electromagnetic product, comprising:

a plurality of devices, each device comprising at least one pair of coplanar magneto-resistive sensors and a third sensor;

each magneto-resistive sensor having a sensitive axis in the plane; and

the third sensor sensitive to an electromagnetic field in a direction perpendicular to the at least one pair of coplanar magneto-resistive sensors,

wherein the electromagnetic product measures the electromagnetic field in three dimensions.

37. An electromagnetic product according to claim 36, wherein the plurality of devices is formed on a substrate.

38. An electromagnetic product according to claim 36, wherein the plurality of devices are formed on substrates arranged in a stack.

39. An electromagnetic product according to claim 36, wherein at least one device comprises giant magneto-resistive sensors and a *Hall effect* sensor, the giant magneto-resistive sensors

and the *Hall effect* sensor arranged about a central point on a substrate to measure orthogonal components of the electromagnetic field.

40. An electromagnetic product according to claim 36, wherein at least one device comprises giant magneto-resistive sensors and a coil, the giant magneto-resistive sensors and the coil arranged about a central point on a substrate to measure orthogonal components of the electromagnetic field.

41. An electromagnetic product according to claim 36, wherein the plurality of devices are arranged in arrays and formed on substrates, the substrates arranged in a stack.

42. An electromagnetic product, comprising:

a plurality of devices, each device comprising a first and a second giant magneto-resistive sensor and a *Hall effect* sensor;

the first and second giant magneto-resistive sensors having a coplanar relationship and arranged in a cruciform about a central point, the first giant magneto-resistive sensor having a first sensitive axis in the plane and measuring the electromagnetic field along the first sensitive axis, the second giant magneto-resistive sensor having a second sensitive axis in the plane and measuring the electromagnetic field along the second sensitive axis, the first and second giant magneto-resistive sensors measuring orthogonal components of the electromagnetic field in an area of the central point;

the third sensor arranged in the area of the central point, the third sensor utilizing the *Hall effect* to measure the electromagnetic field in a direction perpendicular to the plane of the first and second giant magneto-resistive sensors; and

the plurality of devices arranged in arrays and formed on substrates, the substrates arranged in a stack.

43. A method of summing electromagnetic field vectors at at least two different locations, comprising:

measuring a field vector at at least two different locations with at least two two-dimensional sensors, each two-dimensional sensor comprising at least two coplanar magneto-resistive sensors, each magneto-resistive sensor having a sensitive axis in the plane of the at least two coplanar magneto-resistive sensors; and

summing each measurement from the at least two two-dimensional sensors.

44. A method of summing electromagnetic field vectors according to claim 43, wherein the step of measuring a field vector comprises measuring at least one of i) a magnitude and ii) a phase of the field vector.

45. A method of summing electromagnetic field vectors according to claim 43, wherein the step of measuring a field vector comprises measuring at least one of i) an electromagnetic field that varies periodically with time and ii) an electromagnetic field that varies sinusoidally with time.

46. A method of subtracting electromagnetic field vectors at at least two different locations, comprising:

measuring a field vector at at least two different locations with at least two two-dimensional sensors, each two-dimensional sensor comprising at least two coplanar magneto-resistive sensors, each magneto-resistive sensor having a sensitive axis in the plane of the at least two coplanar magneto-resistive sensors; and

detecting the difference between each measurement from the at least two two-dimensional sensors.

47. A method of summing electromagnetic field vectors according to claim 46, wherein the step of measuring a field vector comprises measuring at least one of i) a magnitude and ii) a phase of the field vector.

48. A method of summing electromagnetic field vectors according to claim 46, wherein the step of measuring a field vector comprises measuring at least one of i) an electromagnetic field that varies periodically with time and ii) an electromagnetic field that varies sinusoidally with time.

49. A method of summing electromagnetic field vectors at at least two different locations, comprising:

measuring a field vector at at least two different locations with at least two three-dimensional sensors, each three-dimensional sensor comprising at least two coplanar magneto-resistive sensors and a third sensor, each magneto-resistive sensor having a sensitive axis in the plane, and the third sensor measuring the electromagnetic field in a direction perpendicular to the plane of the at least two coplanar magneto-resistive sensors; and

summing each measurement from the at least two three-dimensional sensors.

50. A method of subtracting electromagnetic field vectors at at least two different locations, comprising:

measuring a field vector at at least two different locations with at least two three-dimensional sensors, each three-dimensional sensor comprising at least two coplanar magneto-resistive sensors and a third sensor, each magneto-resistive sensor having a sensitive axis in the plane, and the third sensor measuring the electromagnetic field in a direction perpendicular to the plane of the at least two coplanar magneto-resistive sensors; and

detecting the difference between each measurement from the at least two three-dimensional sensors.

51. A product for detecting flaws in electrically conductive specimens, comprising:

a coil for inducing an electromagnetic field in a specimen; and

a spin-dependent tunneling sensor having a sensitive axis,

wherein a flaw creates a perturbation in the induced electromagnetic field and the spin-dependent tunneling sensor detects this perturbation.

52. A product according to claim 51, wherein the coil has a circular cross-section and an axis of symmetry perpendicular to the cross-section.

53. A product according to claim 51, wherein the spin-dependent tunneling sensor is disposed on an axis of symmetry of the coil.

54. A product according to claim 51, wherein the sensitive axis of the sensor is orthogonal to an axis of symmetry of the coil.

55. A product according to claim 51, wherein the coil is a flat coil.

56. A product for detecting flaws in electrically conductive specimens, comprising:

a coil for inducing an electromagnetic field in a specimen; and

at least two coplanar magneto-resistive sensors, each magneto-resistive sensor having a sensitive axis in the plane and measuring the electromagnetic field along the sensitive axis,

wherein a flaw creates a perturbation in the induced electromagnetic field, and the at least two magneto-resistive sensors detect this perturbation.

57. A product according to claim 56, wherein the coil comprises a flat coil.

58. A product according to claim 56, further comprising a third sensor for measuring the electromagnetic field in a direction perpendicular to the plane.

59. A product according to claim 56, wherein the at least two coplanar magneto-resistive sensors and the coil are formed on a substrate.

60. A product according to claim 56, further comprising a third sensor for measuring the electromagnetic field in a direction perpendicular to the plane, and wherein the at least two coplanar magneto-resistive sensors, the third sensor, and the coil are formed on a substrate.

61. A product according to claim 56, wherein the at least two coplanar magneto-resistive sensors comprise giant magneto-resistive sensors orthogonally arranged about a central point and arranged external to the coil, with the coil also having an axis of symmetry about the central point, the axis of symmetry of the coil being orthogonal to the plane of the sensors.

62. A product according to claim 56, wherein the at least two coplanar magneto-resistive sensors comprise giant magneto-resistive sensors orthogonally arranged about a central point, the coil also having an axis of symmetry about the central point, the axis of symmetry of the coil being orthogonal to the plane of the sensors, with the giant magneto-resistive sensors and the coil formed on a substrate.

63. A product according to claim 56, further comprising a *Hall effect* sensor for measuring the electromagnetic field in a direction perpendicular to the plane, wherein the at least two coplanar magneto-resistive sensors comprise giant magneto-resistive sensors orthogonally arranged about a central point, with the coil also having an axis of symmetry about the central point, the axis of symmetry of the coil being orthogonal to the plane of the sensors.

64. A product for detecting flaws in specimens, comprising:

a plurality of devices, each device comprising at least one coil and at least one two-dimensional magneto-resistive sensor, the at least one coil for inducing an electromagnetic field in a specimen, the at least one two-dimensional magneto-resistive sensor comprising a first magneto-resistive sensor and a second coplanar magneto-resistive sensor, the first

magneto-resistive sensor and the second magneto-resistive sensor each having a sensitive axis in the plane and measuring the electromagnetic field along the sensitive axis,

wherein a flaw creates a perturbation in the induced electromagnetic field, and the at least one two-dimensional magneto-resistive sensor detects this perturbation.

65. A product according to claim 64, wherein each device further comprises a third sensor measuring the electromagnetic field in a direction perpendicular to the plane.

66. A product according to claim 64, wherein the plurality of devices are arranged in a one-dimensional array.

67. A product according to claim 64, wherein the plurality of devices are formed on a substrate.

68. A product according to claim 64, wherein the plurality of devices are arranged in a two-dimensional array.

69. A product according to claim 68, wherein the plurality of devices are formed on a substrate.

70. A product according to claim 68, wherein the at least one two-dimensional magneto-resistive sensor comprises giant magneto-resistive sensors orthogonally arranged about a central point, with the at least one coil having an axis of symmetry about the central point, the axis of symmetry of the coil being orthogonal to the plane of the sensors.

71. A product according to claim 68, wherein the at least one two-dimensional magneto-resistive sensor and the coil are formed on a substrate.

72. A product according to claim 68, wherein each device further comprises a *Hall effect* sensor measuring the electromagnetic field in a direction perpendicular to the plane, with the at least

one two-dimensional magneto-resistive sensor, the *Hall effect* sensor, and the coil formed on a substrate.

73. A product according to claim 64, wherein the plurality of devices are arranged in a three-dimensional array, the three-dimensional array comprising a stack of two-dimensional arrays, each two dimensional array comprising at least one device formed on a substrate.

74. A product according to claim 73, wherein the at least one two-dimensional magneto-resistive sensor comprises giant magneto-resistive sensors orthogonally arranged about a central point, with the at least one coil also having an axis of symmetry about the central point, the axis of symmetry of the coil being orthogonal to the plane of the sensors.

75. A probe for detecting a flaw, such as a crack, at an edge of an electrically conductive specimen of a specific shape, comprising:

an excitation coil similarly shaped to the specimen for inducing eddy currents in the specimen; and

at least one magneto-resistive sensor located above the edge of the specimen, the at least one magneto-resistive sensor having a sensitive axis tangentially-aligned with the edge of the specimen,

wherein the flaw at the edge creates a perturbation in the induced eddy currents, and the at least one magneto-resistive sensor detects this perturbation.

76. A probe according to claim 75, wherein the magneto-resistive sensor comprises giant magneto-resistive sensors.

77. A probe according to claim 75, wherein the magneto-resistive sensor comprises spin dependent tunneling sensors.

78. A probe according to claim 75, further comprising an array of magneto-resistive sensors, each magneto-resistive sensor in the array having a sensitive axis tangentially-aligned with the edge of the specimen.

79. A probe current probe according to claim 78, wherein each magneto-resistive sensor in the array comprises giant magneto-resistive sensors.

80. A probe according to claim 78, wherein each magneto-resistive sensor in the array comprises spin dependent tunneling sensors.

81. A probe according to claim 78, wherein the array of magneto-resistive sensors has a circular shape.

82. A probe according to claim 78, wherein the array of magneto-resistive sensors is formed on a substrate.

83. A probe according to claim 75, wherein the excitation coil has a circular shape.

84. A probe according to claim 75, further comprising means for biasing the magneto-resistive sensor to compensate for the earth's magnetic field.

85. An eddy current probe for detecting a flaw in an electrically conductive specimen, comprising:

a coil for inducing eddy currents in the specimen, the coil having a cross-section and an axis of symmetry within a plane of the cross-section; and

a magneto-resistive sensor having an axis of sensitivity coplanar with the cross-section and orthogonal to the axis of symmetry, with the magneto-resistive sensor disposed on the axis of symmetry and at least one of i) exterior to the coil and ii) interior to the coil,

wherein the flaw creates a perturbation in the induced eddy currents, and the magneto-resistive sensor detects this perturbation.

86. An eddy current probe according to claim 85, wherein the magneto-resistive sensor comprises a giant magneto-resistive sensor.

87. An eddy current probe according to claim 85, wherein the magneto-resistive sensor comprises a spin dependent tunneling sensor.

88. An eddy current probe for detecting a flaw in an electrically conductive specimen, comprising:

a coil for inducing eddy currents in the specimen, the coil having a cross-section and an axis of symmetry within the plane of the cross-section; and

an array of magneto-resistive sensors, with each magneto-resistive sensor having an axis of sensitivity coplanar with the cross-section and orthogonal to the axis of symmetry, the array of magneto-resistive sensors disposed on the axis of symmetry and at least one of i) exterior to the coil and ii) interior to the coil,

wherein the flaw creates a perturbation in the induced eddy currents, and the magneto-resistive sensor detects this perturbation.

89. An eddy current probe according to claim 88, wherein the array of magneto-resistive sensors comprises a giant magneto-resistive sensor.

90. An eddy current probe according to claim 88, wherein the array of magneto-resistive sensors comprises a spin dependent tunneling sensor.

91. An eddy current probe according to claim 88, wherein the array of magneto-resistive sensors is formed on a substrate.

92. An eddy current probe according to claim 88, wherein the cross-section of the coil has a "D"-shape.

93. An eddy current probe according to claim 88, wherein the cross-section of the coil has a double "D"-shape.

94. A method of detecting a crack initiating from an edge of a hole, comprising:

orienting an eddy current probe with the hole, the eddy current probe having a circular coil and a magneto-resistive sensor, the circular coil substantially concentrically aligned to the hole, and the magneto-resistive sensor having a sensitive axis substantially tangentially aligned to the edge of the hole; and

scanning the eddy current probe such that the crack produces a perturbation and the magneto-resistive sensor detects the perturbation.

95. A method of detecting a crack according to claim 94, wherein the step of orienting an eddy current probe with the hole includes substantially tangentially aligning the sensitive axis of a giant magneto-resistive sensor to the edge of the hole.

96. A method of detecting a crack according to claim 94, wherein the step of orienting an eddy current probe with the hole includes substantially tangentially aligning the sensitive axis of a spin dependent tunneling sensor to the edge of the hole.

97. A method of detecting a crack initiating from an edge of a specimen, comprising:

orienting an eddy current probe to the specimen, the eddy current probe having a coil and a magneto-resistive sensor, the coil for inducing eddy currents in the specimen, the coil having a cross-section defining an axis of symmetry, the magneto-resistive sensor having an axis of sensitivity coplanar with the cross-section and orthogonal to the axis of symmetry,

with the magneto-resistive sensor disposed at the axis of symmetry and at least one of i) exterior to the coil and ii) interior to the coil, the probe oriented with the cross-section parallel to the specimen and with the axis of sensitivity parallel to the edge of the specimen; and

scanning the probe along the edge of the specimen with the axis of sensitivity parallel to the edge.

98. A method of detecting a crack according to claim 97, wherein the step of orienting an eddy current probe to the specimen includes orienting the eddy current probe to an edge of a hole, with the probe oriented with the axis of sensitivity tangential to the edge of the hole.

99. A method of detecting a crack according to claim 98, wherein the step of scanning the probe along the edge of the specimen includes rotating the probe around the edge of the hole with the sensitive axis tangential to the edge of the hole.